AR-001-480

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

ELECTRONICS RESEARCH LABORATORY

TECHNICAL REPORT

ERL-0061-TR

A BRIGHTNESS LINEARIZATION TECHNIQUE FOR A THERMAL IMAGER

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S U M M A R Y

This paper describes the brightness linearization technique used in the video processing for a thermal imager. A wide bandwidth log-antilog circuit is developed. This circuit converts the linear video signal to a power law which directly compensates for the gamma of the cathode ray tube display.

Approved for Public Release

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1. INTRODUCTION

The DRCS Sector Scanner is an infra-red imaging system using a single detector which is made to scan in a two dimensional raster format. After signal processing the information is presented to the observer on a high resolution cathode ray tube display. (See reference 1). The inherent non linear brightness function of the display tube results in expansion of the displayed signals at high video levels. A logarithmic amplifier was incorporated to provide some form of video compression thus allowing full utilization of the maximum output of the display system. (See reference 2). It became apparent, however, that this was not sufficient especially at low to medium signal levels and so a brightness linearization circuit was also incorporated.

The brightness linearization technique and the design and performance of the circuit which was used in the DRCS Sector Scanner are described in this paper.

2. VIDEO PROCESSING IN THE DRCS SECTOR SCANNER MK 2

A complete description of the video channel is given because several changes were made to the original design whilst the brightness linearization circuit was being incorporated.

The signals at the infra-red detector (refer to figure 1) are extremely low level and they are amplified by a low noise amplifier and line driver stage. They are then sent down the cable connecting the scanner head to the console unit. The next stage is a line receiver and buffer amplifier which has a bandwidth that can be varied to match the scanning rate of the system. The scanning rate can be varied over a range greater than five to one and since the bandwidth required to transmit the video information is directly dependent on the scanning rate, the bandwidth is varied to minimize the background noise of the system for each scanning speed.

The clamp circuit then restores a d.c. component to the a.c. signal. The magnitude of the d.c. component can be varied by means of the "back level control" which is situated on the console front panel. The signal is then conditioned in a logarithmic amplifier (see reference 2). In the latest design a modification was added to this circuit which allows the logarithmic stage to be bypassed as this was found to be advantageous in certain situations, particularly when dealing with extremely low level infra-red signals. The logarithmic amplifier is followed by the brightness linearization circuit, the signals from the logarithmic amplifier being buffered by a variable gain (or contrast) amplifier. Again an option is provided for bypassing the non linear circuit thus enabling operation in a linear mode.

Finally the cathode ray tube display is driven by a wide band transistor amplifier which also incorporates the function of video blanking and provides a bright up input for adding the centre line and cursor marker pulses. The whole circuit is now d.c. coupled from the d.c. clamp circuit to the CRT display and consequently the d.c. restoration circuit as used in the original video drive stage was deleted. See figure 2 for the actual video processing circuit diagram.

3. CATHODE RAY TUBE DISPLAY

Tests were carried out on one of the Sector Scanner Mk 2 displays (note this equipment uses a twin CRT display) both before and after the incorporation of the brightness linearization circuit.

The actual tube used is a 14 inch, 70° CRT type number 360 MA11 P38 manufactured by Thomas Electronics Incorporated. It uses a special high resolution gun in order to achieve the degree of performance required for the sector scanner. The grid to cathode cut-off voltage is between 50 and 60 V depending on the operating conditions.

In the sector scanner the CRT display is used in what is effectively a common grid mode with the video signal, being applied to the cathode and the first or control grid being held at a voltage more negative than the cathode. Brightness control was achieved by varying the grid bias, but in this latest design this control was changed to a preset one and the brightness can now be varied by adjusting the black level control. The preset brightness control is adjusted so that the background of the display is just discernable when the smallest infra-red signal is being detected.

The actual brightness characteristic of one of the display tubes was measured using a pattern generator which was built to suit the particular requirements of the sector scanner. (See figure 3 for the circuit diagram). The technique used was to have the sector scanner running at a fixed scanning rate and to then pick off the appropriate frame and line pulses which were used to synchronise the pattern generator. The generator staircase waveform was injected into the video channel (used in the linear mode) and the resulting CRT display brightness levels were monitored by means of a simple, instantaneous reading light meter. (See figure 3 for the circuit diagram).

The measured results are shown in figure 4 along with the best fit theoretical curve which indicated that the CRT display had a gamma equal to 2.5. For the best conditions the useful video drive was established as 30 V peak to peak.

4. DESIGN CONSIDERATIONS FOR THE BRIGHTNESS LINEARIZATION CIRCUIT

4.1 Bandwidth

The bandwidth of the video channel must be greater than the signal bandwidth from the detector. For the present detector and the scanning rates that are used this has been established to be 1 MHz. The low noise pre-amplifier and the other amplifiers in the video chain all have bandwidths greater than this.

4.2 Time constant

The manufacturer's data for the infra-red detector gives the equivalent electrical time constand of 0.3 μs. Any circuits in the video processing channel should not degrade this time constant.

4.3 Dynamic range

An estimate of a minimum dynamic range (i.e. ratio of maximum signal to minimum signal) of 60 dB or 1000:1 has been used previously in the design of the sector scanner low noise pre-amplifier and logarithmic amplifier.

4.4 Compatability

The brightness linearization circuit is situated immediately after the logarithmic amplifier and it must operate with signals in the range 1 mV to 1 V.

4.5 Noise

Great care was taken in the design of the low noise pre-amplifier to ensure that the detector was the predominant source of noise in the system. However it is still essential that the noise figure of the brightness linearization circuit is low enough not to degrade the signal to noise ratio of the whole system. The wide-band noise levels at the input to the brightness linearization circuit are typically 30 mVp-p or 6 mV r.m.s.

4.6 Temperature stability

Because all of the circuitry after the d.c. clamp section is d.c. coupled it is important that the circuits do not drift excessively with temperature.

A slight variation is acceptable however because the operator can vary the black level control to alter the display brightness.

In practice the operator is continually adjusting the black level control because the d.c. clamp pulse occurs when the detector is picking up radiation from the scanner head and it has been found that this radiation varies significantly as the internal temperature changes.

5. BRIGHTNESS LINEARIZATION TECHNIQUE

A number of possible methods exist which enable a non linear analogue signal to be converted so that it exhibits a linear transfer function. Several of the latest techniques involve digital methods whereby the non linear form is measured and stored as a "look-up' table and the appropriate correction made for each input level. These systems have the disadvantage of being rather complex and would be very expensive for the speed and resolution that is required in this application.

Of the analogue methods available, the piece-wise linear approximation technique was discarded because of the lack of flexibility. It is difficult to alter the parameters of the transfer function once they have been designed into the circuit. A technique which overcame this limitation and which satisfied all of the design requirements discussed above was developed using two conventional non linear function generators, the logarithmic amplifier and the antilogarithmic or exponential function generator.

The basic block diagram of the brightness-linearization technique is shown in figure 5. The input signal is transformed via a logarithmic converter so that

$$V_2 = \log V_1$$

then the signal is attenuated by a factor k where $k \leqslant 1$

i.e. $V_3 = k \; V_2$

$= k \; \log V_1$ which may be rewritten as

$V_3 = \log V_1{}^k$

Signal voltage V_3 is then transformed through an anti-logarithmic stage so that

$$V_4 = \text{antilog } V_3$$

$$= \text{antilog } (\log V_1{}^k)$$

i.e. $V_4 = V_1{}^k$

i.e. the output voltage is the input signal raised to a power k.

For example, if k = 0.4, that is a 2.5:1 attenuation then

$V_4 = V_1{}^{0.4}$ and if V_4 is the voltage used to drive the CRT display which has been established to have a $\gamma = 2.5$ then

brightness $\alpha \; V_4{}^{2.5}$

or $\alpha \; V_1$ and a linear relation exists between the display brightness and the input signal.

In actual practice there are a number of offsets and constants which must also be considered and these will be discussed in a later section.

The main advantage of this technique is the ease with which the power constant can be changed so altering the expression obtained and allowing it to be trimmed to match the CRT display tube characteristic exactly. In practice the attenuator is a variable potentiometer which is easily adjusted to give the correct shape.

6. CIRCUIT DESCRIPTION

6.1 Logarithmic stage

The first requirement in synthesizing the brightness-linearization technique described above is the logarithmic stage. Various configurations for generating logarithmic stages are available however the most difficult design criterion to satisfy was the frequency response. Most precision systems employ an amplifier with a non linear feedback element which is typically either a transistor or a diode. See figures 6 and 7. A transistor must be used in the grounded base configuration to eliminate errors due to base current. This increases the loop gain and more compensation is necessary to prevent oscillation and the logarithmic converter is necessarily slow. The diode however can be operated with high currents thus keeping its dynamic resistance low and ensuring a fast response for the whole system. The high current operatioı also has the advantage of minimising the effect of the reverse saturation current thus ensuring true logarithmic performance.

As mentioned previously the sector scanner video channel already uses a logarithmic amplifier to provide some form of video compression. The technique used in that circuit employs a Texas Instruments integrated circuit which provides parallel signal paths with multiple logarithmic elements and suitable attenuators to give an overall dynamic range of greater than 60 dB V. An alternative approach was used in the brightness linearization circuit because the two diode non linear elements which were the most sensitive temperature components could be placed in close proximity in the constant temperature oven thus reducing the stability problems. As well as this the temperature drift of the logarithmic and the antilogarithmic diode amplifiers was complimentary and this further increased the overall temperature stability.

6.1.1 Diode characteristics

The relationship between the forward current and the applied voltage for a diode is obtained from classical semiconductor p-n junction diode theory.

$$I = I_s \left(\exp\left(\frac{qV}{KT}\right) - 1\right)$$

where I = forward current

I_s = reverse saturation current

q = electron charge (1.6×10^{-19} coulomb)

V = applied bias voltage

K = Boltzmann's constant (1.38×10^{-23} watt sec/K)

T = absolute temp. of diode.

If the saturation current is small

$$I = I_s \exp\left(\frac{qV}{KT}\right)$$

or

$$V = \frac{KT}{q} \ln I + \text{constant}$$

i.e. the diode voltage is directly proportional to the natural logarithm of the forward current. Note that it is also directly proportional to the temperature of the diode. This problem was overcome by operating the diode at a constant temperature and a small low power crystal oven proved ideal for this purpose. In fact when the logarithmic amplifier is used in conjunction with the antilogarithmic stage most of the temperature induced effects tend to cancel. Both the diode used for generating the logarithmic function and the diode used for generating the antilogarithmic function were enclosed in the same temperature controlled oven.

6.1.2 Analysis of logarithmic stage

By neglecting the constant which is just a fixed offset a simplified analysis of the logarithmic stage shown in figure 7 gives

$$V_2 = -\frac{KT}{q} \ln I$$

and $I = \dfrac{V_1}{R_L}$

hence $V_2 = -\dfrac{KT}{q} \ln \left(\dfrac{V_1}{R_L}\right)$

i.e. the linear input voltage (V_1) is converted to a logarithmic output voltage (V_2).

If the actual scaling factors and offset constants are now included this becomes

$$V_2 = -C \ln \left(\frac{V_1}{R_L}\right) - C_L$$

where $C = \dfrac{KT}{q}$

$= 0.03$ for $T = 353$ K

$C_L = 0.73$ volts

$R_L = 470$ ohms

These values were selected to give a suitable diode operating current and hence the correct dynamic impedance in the circuit thus ensuring that the dynamic range and frequency response conditions were satisfied. The offset voltages also ensure that the signals are of the correct polarity because logarithms can only be computed for signals with positive values. A graph of the transfer function is shown in figure 8 (lower right hand quadrant).

6.2 Attenuation stage

As explained previously the amount of attenuation determines the magnitude of the power in the overall transfer function to which the input signal is raised. A value of 2.5 was required for the particular tube that was tested.

i.e. $k = \dfrac{1}{2.5}$

hence $V_3 = \dfrac{V_2}{2.5} - C_A$ where C_A is an offset constant

or $V_3 = k\, C \ln \left(\dfrac{V_1}{R_L}\right) - C_L - C_A$

See figure 8 (lower left hand quadrant) for a graph of this transfer function.

6.3 Antilogarithmic stage

To obtain the antilogarithmic transfer function the circuit configuration shown in figure 9 was utilized. In this circuit the input voltage is applied to the diode and this induces an exponential input current to the operational amplifier. The feed back resistor (R_{AL}) transduces this current to an output voltage.

6.3.1 Analysis of the antilogarithmic stage

An analysis of the antilogarithmic circuit can be made using the semi-conductor diode expressions shown above. With the notation shown in figure 9

$$V_3 = -\frac{KT}{q} \ln I$$

and $$I = \frac{V_4}{R_{AL}}$$

hence $$V_3 = -\frac{KT}{q} \ln \left(\frac{V_4}{R_{AL}}\right)$$ which may be rewritten as

$$V_4 = R_{AL} \text{ antiln } \left(\frac{-V_3}{C}\right)$$

where $C = \frac{KT}{q}$ as before.

i.e. the output voltage is proportional to the antilogarithm of the input voltage.

If the actual scaling factors and offset voltages are now incorporated the expression becomes

$$V_4 = R_{AL} \text{ antiln } \left(\frac{V_R - V_3}{C}\right) + V_R$$

where V_R is the fixed reference voltage which is applied to the non inverting input of the operational amplifier.

$V_R = 0.33$ volts

$R_{AL} = 47$ ohms

A graph of this transfer function is shown in figure 8 (top left hand quadrant).

6.4 Brightness linearization transfer function

Combining all of the transfer functions developed in the previous sections results in an expression for the output voltage (V_4) related to the input voltage (V_1).

$$V_4 = R_{AL} \text{ antiln } \left(\frac{V_R + k\,C \ln \left(\frac{V_1}{R_L}\right) + C_L + C_A}{C}\right) + V_R$$

$$= R_{AL} \text{ antiln } \left(\ln \left[\frac{V_1}{R_L}\right]^k + \left(\frac{V_R + C_L + C_A}{C}\right) \right) + V_R$$

$$= \left(\frac{R_{AL}}{R_L^{\,k}}\right) \left(\exp \left(\frac{V_R + C_L + C_A}{C}\right) \right) \left(V_1^{\,k}\right) + V_R$$

Note that the magnitudes of the reference and offset voltage also influence the overall scaling factor of the brightness linearization transfer function.

With the appropriate values substituted the expression becomes

$$V_4 = 1.12\, V_1^{\,0.4} + 0.33 \qquad 0 < V1 \leqslant 6.8 \text{ volts}$$

See figure 8 (top right hand quadrant) for a graph of this function.

7. SYNTHESIS OF THE BRIGHTNESS LINEARIZATION TRANSFER FUNCTION

The actual circuit which was used to generate the brightness linearization transfer function is shown in figure 2. (The brightness linearization circuit starts at the video gain or contrast control and finishes at test point X5).

The first and final stages are linear amplifiers to provide the required amount of gain and buffer action and they allow the circuit to interface with the existing sector scanner video channel.

The operational amplifiers are National type LH0032 which are ultra fast high input impedance differential input operational amplifiers. They are ideal for use in video amplifiers for gain setting and analogue function shaping. One lower performance LM318 operational amplifier was used as a unity gain buffer. A 1N914 diode (V_5 in figure 2) was used as a clipper to limit the magnitude of the large negative signals that can occur when the black level control is adjusted for viewing high temperature targets.

8. CIRCUIT CONSTRUCTION AND APPLICATION

The circuit was constructed on an experimental circuit card and it performed well after taking the usual precautions of bypassing the supply rails at the individual integrated circuits and frequency compensating the operational amplifiers. The actual layout was surprisingly not critical and the stability was checked by observing the overshoot and ringing at high and low signal levels.

After bench testing, the various performance figures were measured and the circuit was installed in the sector scanner MK 2. Some rearrangement of the sector scanner wiring and card layouts had to be made to enable the brightness linearization circuit to be incorporated into the console. A method was devised whereby in the event of a failure of the brightness linearization circuit the original system could be restored as no spare brightness linearization card had been made at that time.

A final test was made of the CRT display brightness both with and without the brightness linearization circuit (see figure 10) and the sector scanner was then used on an extensive night vision trial off the eastern coast of Queensland and N.S.W. During this trial the sector scanner electronics performed exceptionally well even under extremely severe environmental conditions. Many subjective impressions were obtained about the value of the brightness linearization circuit and these and other comments indicated that the circuit improved the display performance under all the observed conditions. This was not the case however with the sector scanner logarithmic amplifier as at many times it was preferable to operate in the linear mode. An externally mounted switch will be provided in the sector scanner Mk 2A so that the operator can easily select either logarithmic or linear mode.

9. PERFORMANCE

9.1 Frequency response

The high frequency performance was measured using a small sine wave signal which was superimposed onto a variable d.c. level. By varying the magnitude of the input d.c. level the bandwidth could be obtained near both ends of the transfer function. A signal to noise ratio of 20 dB (10:1) was used for the a.c. sine wave.

The 3 dB bandwidth was 1.3 MHz at the maximum output and 1.6 MHz at the minimum output. The low frequency performance extends down to d.c.

9.2 Time constant

A small square wave (S/N = 20 dB) was also superimposed onto a variable d.c. level and used as an input to measure the rise time of the circuit.

At the maximum output the 10-90% rise time was 0.3 μs.

At the minimum output the 10-90% rise time was 0.2 μs.

The time constant can then be obtained using the expression

$$\tau = \frac{t\ (10 - 90\%)}{2.2}$$

At the maximum output the time constant was 0.14 μs.

At the minimum output the time constant was 0.09 μs.

9.3 Noise

Traditionally the noise levels of an amplifier are always referred back to the input even though the actual measurements are made on the output noise. However in a non linear circuit it is difficult to do this because both the gain and the frequency response vary with the input signal. In the case of the brightness linearization circuit a comparison was made of the output noise levels for a d.c. voltage applied at the input and the output noise levels which were measured with the circuit operating in the sector scanner. (The infra-red detector was viewing a uniform ambient temperature source).

9.3.1 Output noise for a d.c. input voltage

At the maximum output the noise was 22 mV p-p or 4.4 mV rms.

At the minimum output the noise was 15 mV p-p or 3 mV rms.

9.3.2 Output noise as measured in the sector scanner

At the maximum output the total output noise was 80 mV p-p or 16 mV rms.

At the minimum output the total output noise was 200 mV p-p or 40 mV rms.

9.3.3 Dynamic range

The maximum output level before any distortion became apparent was 1.9 V hence the dynamic range is

$$\frac{1.9\ \text{V}}{3\ \text{mV}} \quad \text{or} \quad 56\ \text{dB}.$$

9.3.4 Linearity

An ideal power law expression will give a straight line when plotted on a log-log graph. The slope of this line will be the magnitude of the power to which the input variable was raised. An actual plot of the output voltage versus the input voltage for the brightness linearization circuit is shown in figure 11. The slope of the best fit straight line through these points is 0.37 or $\frac{1}{2.7}$. The maximum deviation of the measured response from this straight line is + 6.7% at 3 mV and - 4.2% at 100 mV input.

10. CONCLUSION

A novel method for generating power law functions has been discussed. The method employs a combination of logarithmic amplifier, attenuation, and antilogarithmic amplifier techniques. The main features of this method are the wide bandwidth and the versatility. In fact the power to which the variable is raised can be changed

simply by altering the potentiometer in the attenuation section of the circuit. This technique was successfully used in a circuit to correct for the non linear brightness characteristic of the cathode ray tube display which is used in the DRCS infra-red sector scanner.

With extra development the circuit could possibly be simplified even further, and more economic integrated circuits used. It could then be made into a very useful large scale integration (L.S.I.) module for general purpose use in wide band analogue function shaping applications as well as for display tube gamma correction.

11. ACKNOWLEDGEMENT

The author would like to thank his Principal Officer, Mr N.K. Jones and his supervisor, Mr G.W. McQuistan for their comments and suggestions.

REFERENCES

No	Author	Title
1	McQuistan, G.W.	"WRE Infra-red Sector Scanners". WRE Tech. Note 1549 (AP) August 1976
2	Poropat, G.V.	"A Logarithmic Video Amplifier for the WRE Sector Scanner". WRE Tech Memo 1470 (AP) October 1975

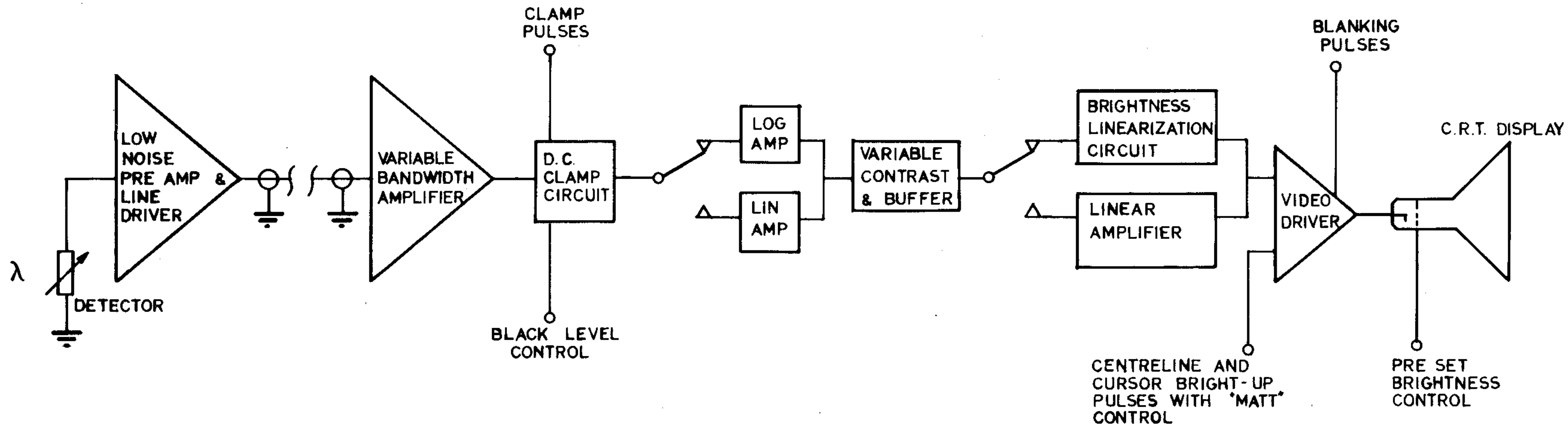

Figure 1. Video processing in the D.R.C.S. Sector Scanner Mk 2A

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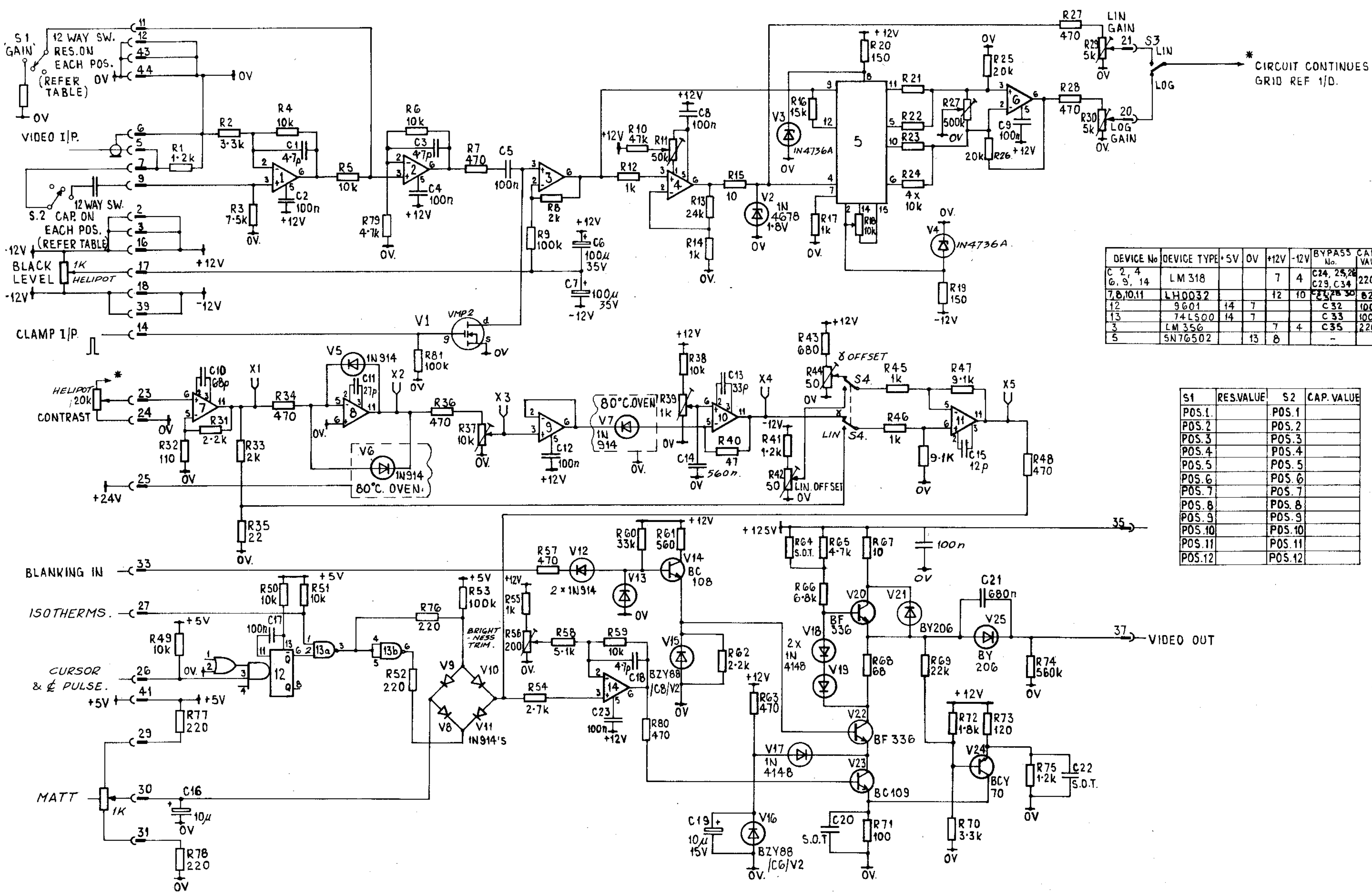
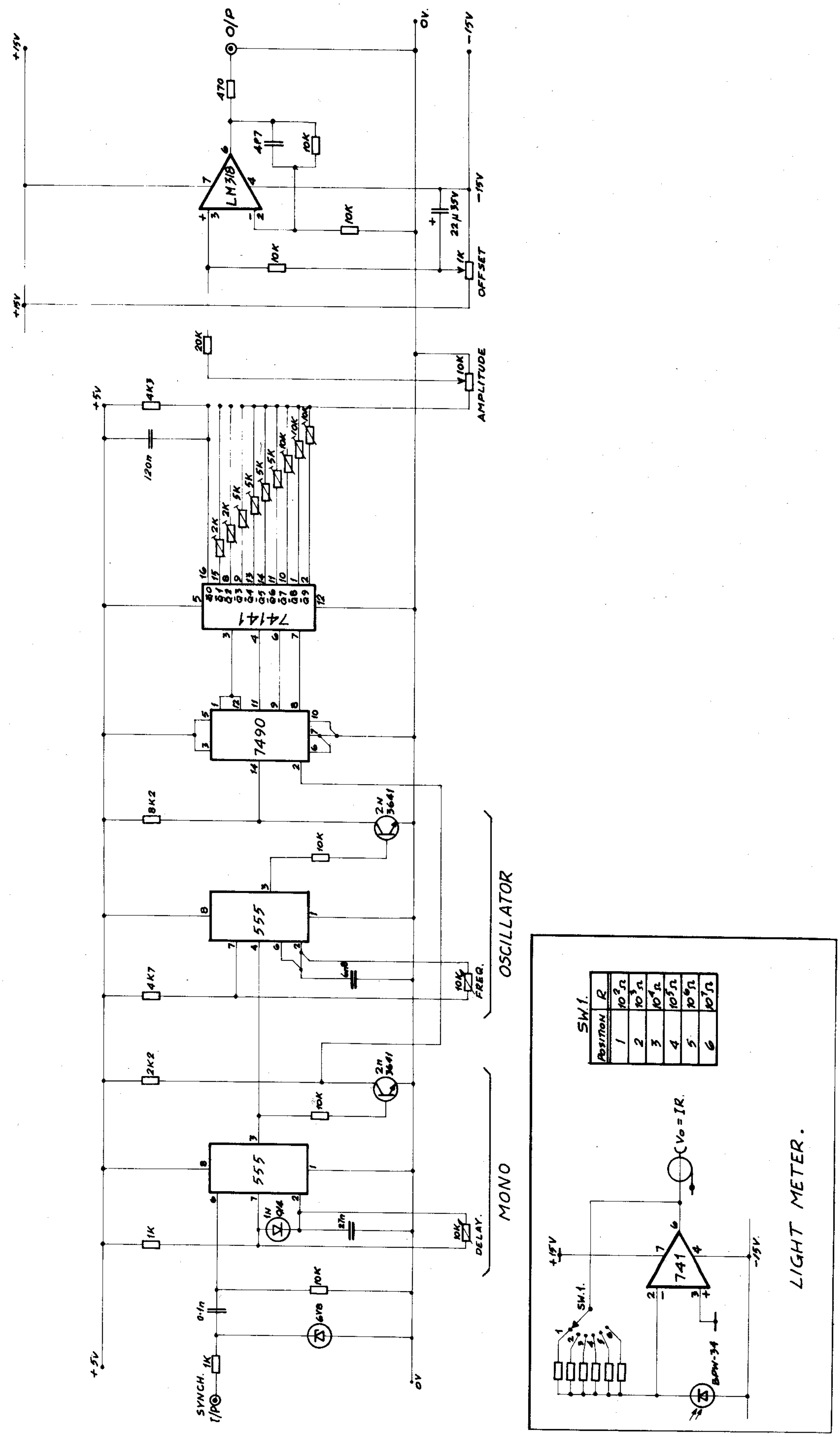
Figure 2



DEVICE No	DEVICE TYPE	+5V	0V	+12V	-12V	BYPASS No.	CAP VALUE
C 2, 4 6, 9, 14	LM 318			7	4	C24, 25, 26 C29, C34	220n
7, 8, 10, 11	LH0032			12	10	C27, 28, 30 C31	82n
12	9601	14	7			C32	100n
13	74LS00	14	7			C33	100n
3	LM 356			7	4	C35	220n
5	SN76502		13	8		–	

S1	RES.VALUE	S2	CAP. VALUE
POS.1		POS.1	
POS.2		POS.2	
POS.3		POS.3	
POS.4		POS.4	
POS.5		POS.5	
POS.6		POS.6	
POS.7		POS.7	
POS.8		POS.8	
POS.9		POS.9	
POS.10		POS.10	
POS.11		POS.11	
POS.12		POS.12	

Figure 2. Circuit diagram of the Sector Scanner video channel



SW.1.	
POSITION	R
1	$10^2\Omega$
2	$10^3\Omega$
3	$10^4\Omega$
4	$10^5\Omega$
5	$10^6\Omega$
6	$10^7\Omega$

Figure 3. Circuit diagram of the pattern generator and light meter

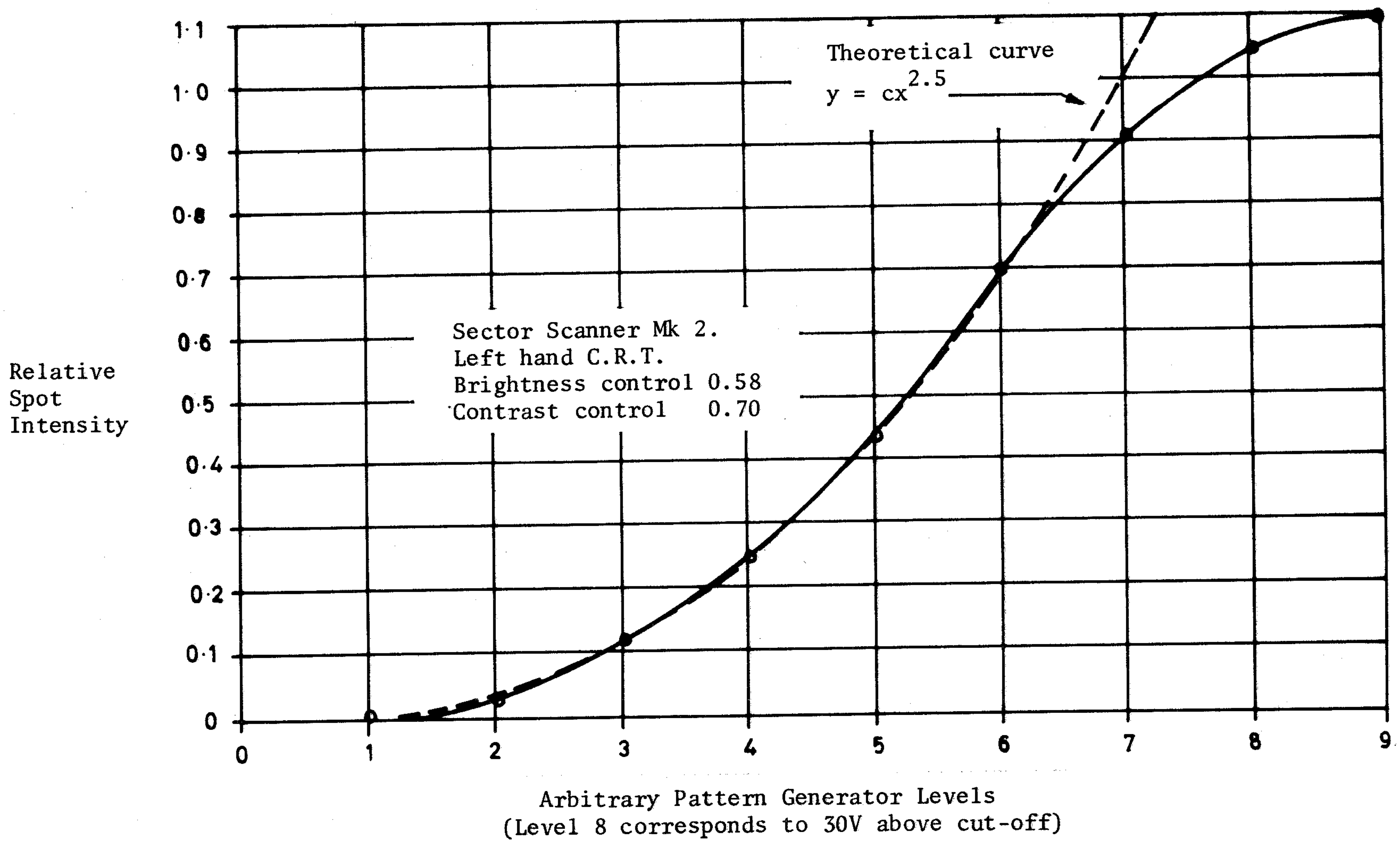


Figure 4. CRT brightness versus input signal

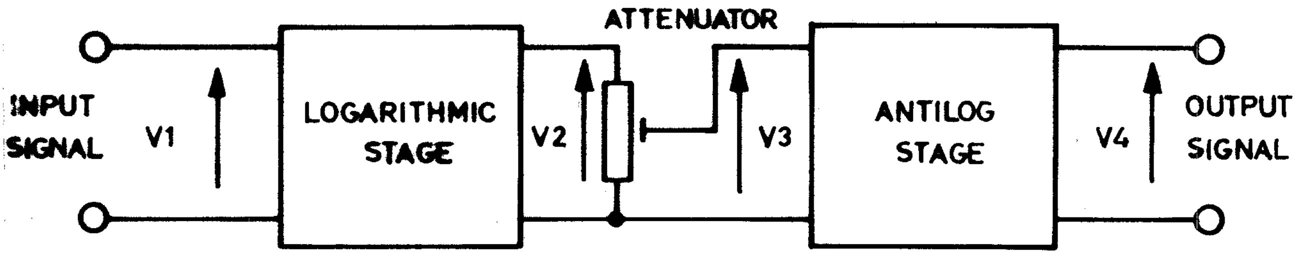


Figure 5. Block diagram of the brightness linearization circuit

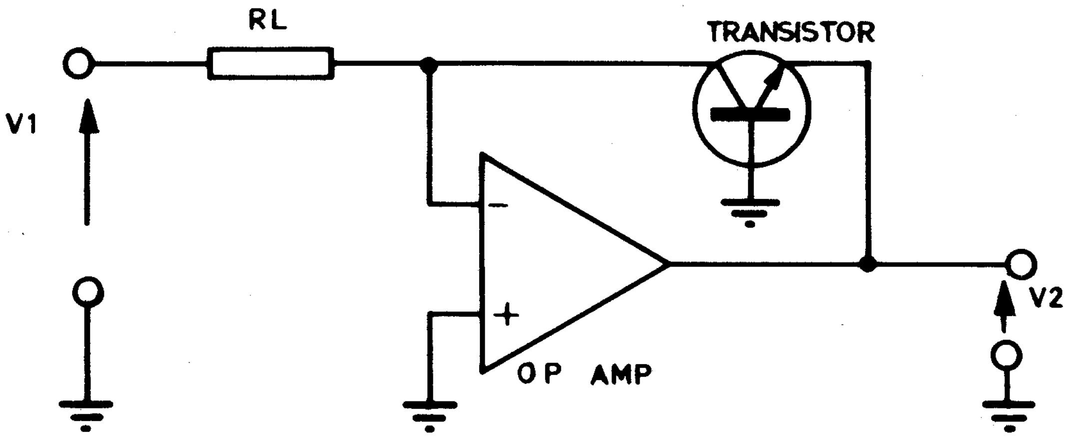


Figure 6. Logarithmic amplifier using a transistor

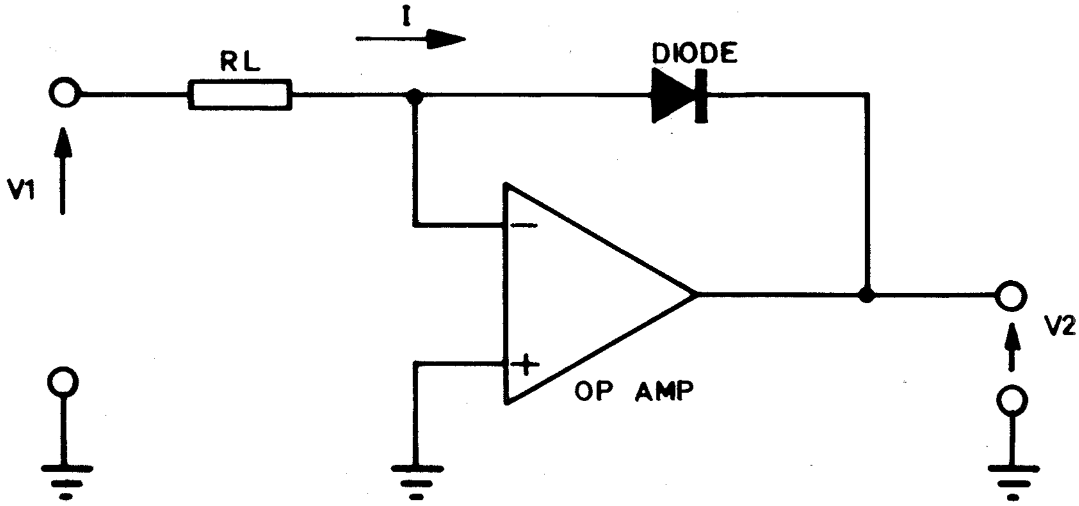


Figure 7. Logarithmic amplifier using a diode

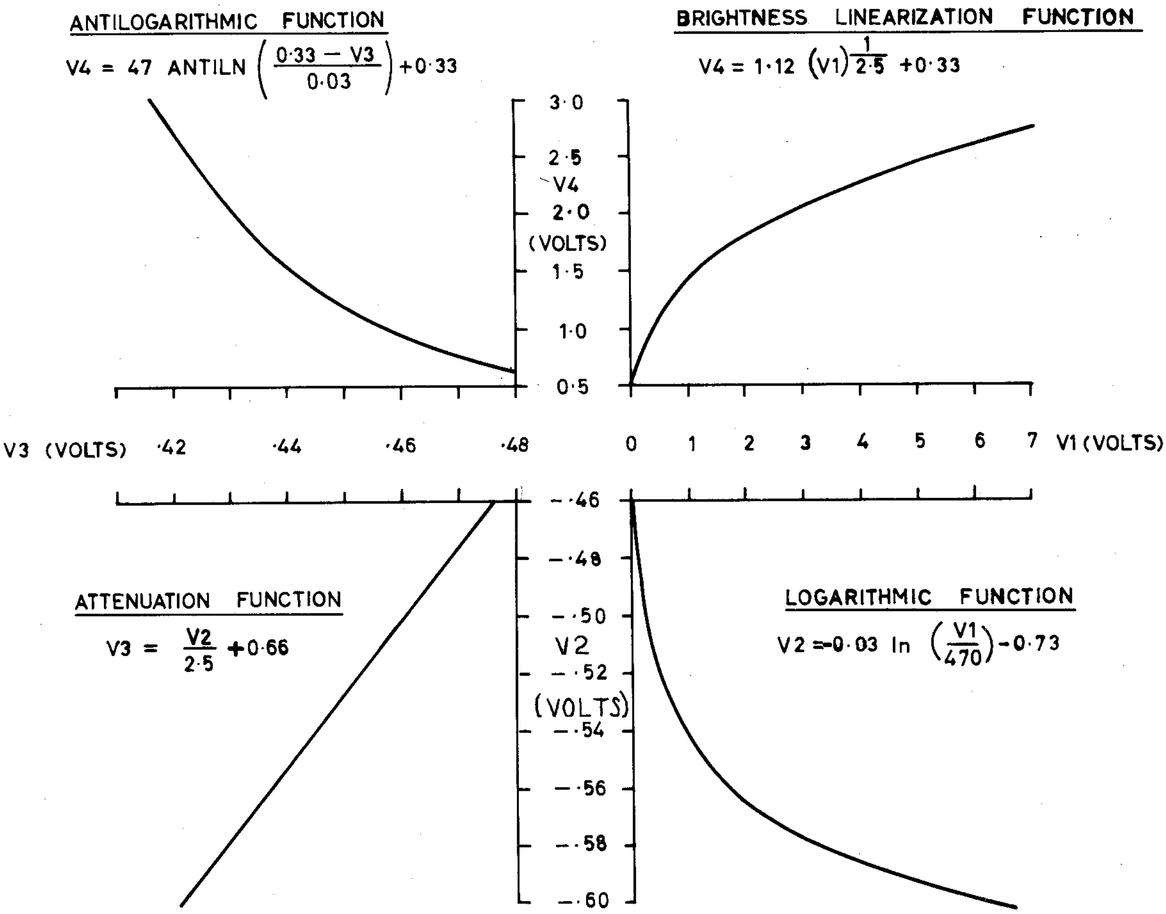


Figure 8. Transfer functions

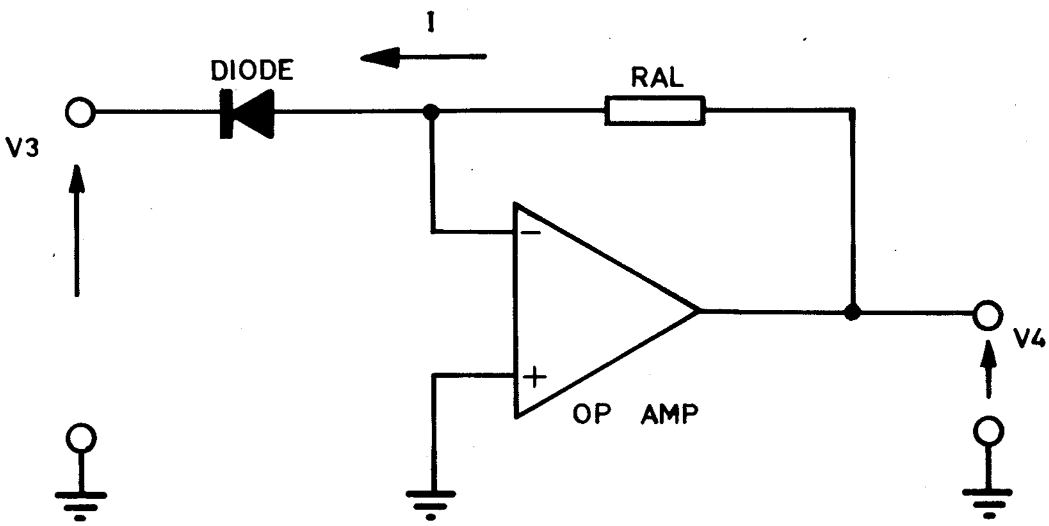


Figure 9. Antilogarithmic amplifier

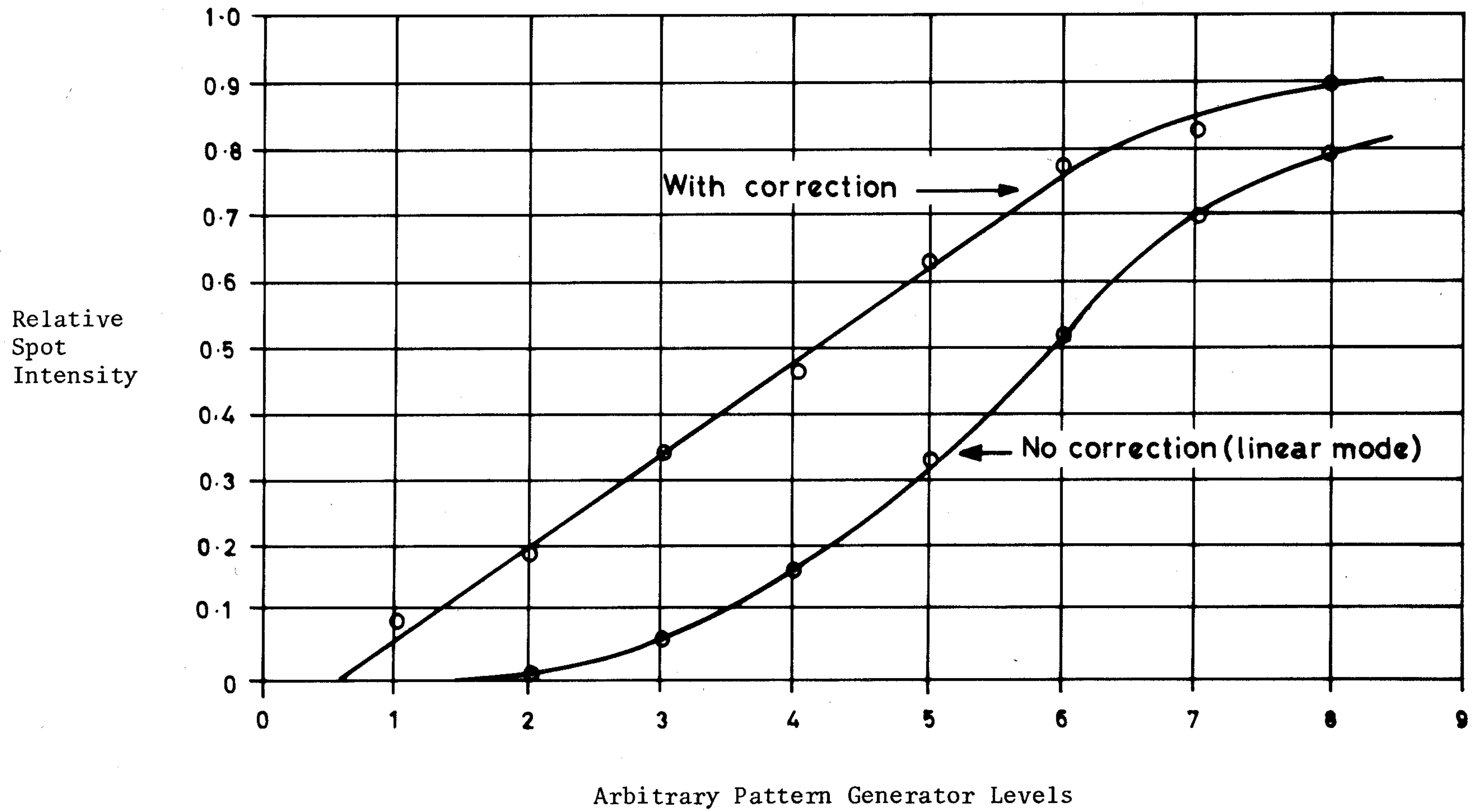


Figure 10. Corrected CRT display brightness versus input signal

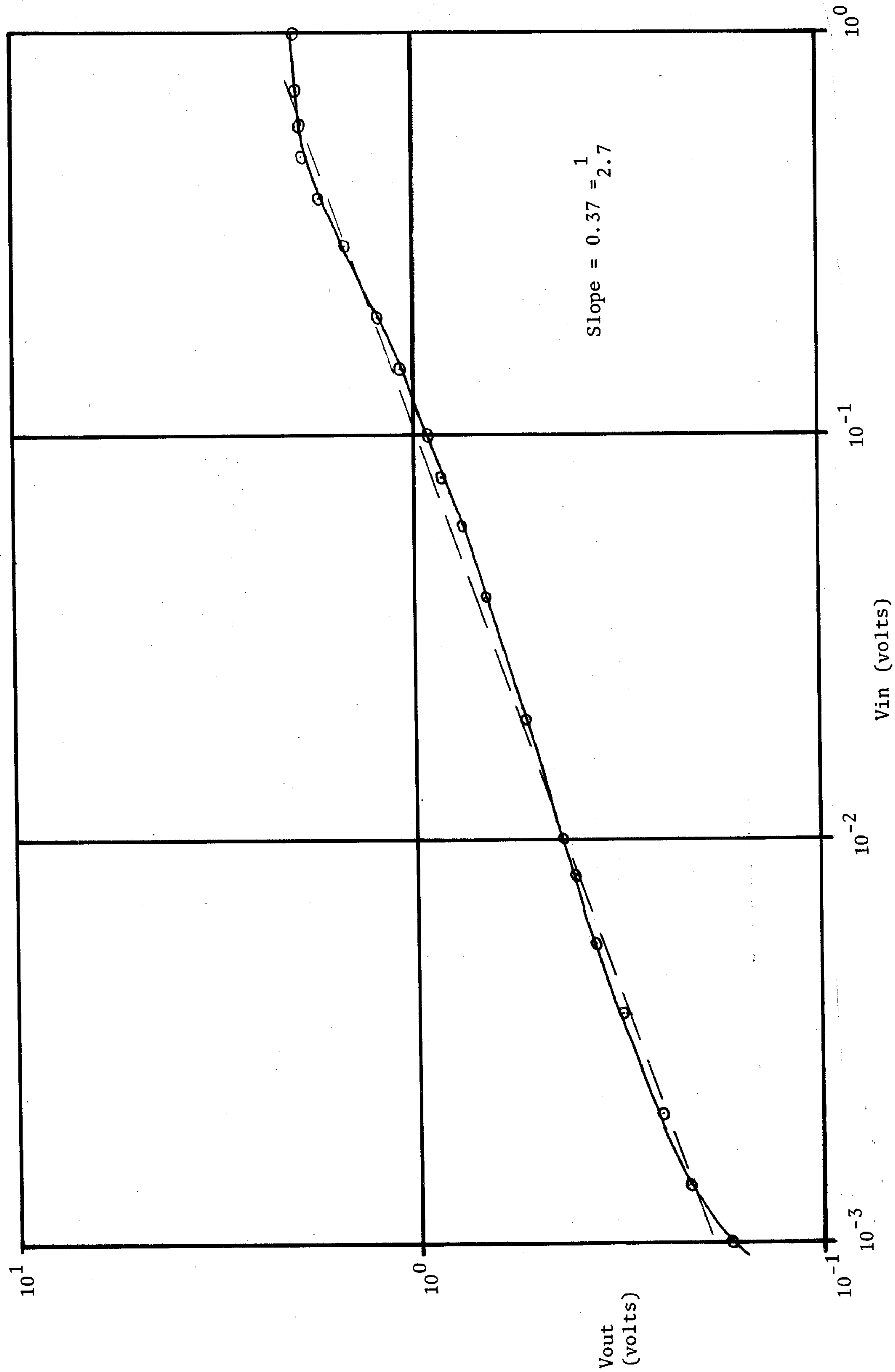


Figure 11. Output voltage versus input voltage of the brightness linearization circuit

DOCUMENT CONTROL DATA SHEET

Security classification of this page: UNCLASSIFIED

1	DOCUMENT NUMBERS
AR Number:	AR-001-480
Report Number:	ERL-0061-TR
Other Numbers:	

2	SECURITY CLASSIFICATION
a. Complete Document:	Unclassified
b. Title in Isolation:	Unclassified
c. Summary in Isolation:	Unclassified

3 TITLE

A BRIGHTNESS LINEARIZATION TECHNIQUE FOR A THERMAL IMAGER

4 PERSONAL AUTHOR(S):

B.W. Rice

5 DOCUMENT DATE:

February 1979

6	
6.1 TOTAL NUMBER OF PAGES	24
6.2 NUMBER OF REFERENCES:	2

7 7.1 CORPORATE AUTHOR(S):

Electronics Research Laboratory

7.2 DOCUMENT SERIES AND NUMBER

Electronics Research Laboratory 0061-TR

8	REFERENCE NUMBERS
a. Task:	RD 72
b. Sponsoring Agency:	DST 68/006

9 COST CODE:

308774

10 IMPRINT (Publishing organisation)

Defence Research Centre Salisbury

11 COMPUTER PROGRAM(S) (Title(s) and language(s))

12 RELEASE LIMITATIONS (of the document):

Approved for Public Release

12.0	OVERSEAS	NO		P.R.	1	A		B		C		D		E	

Security classification of this page: UNCLASSIFIED

Security classification of this page: UNCLASSIFIED

13 ANNOUNCEMENT LIMITATIONS (of the information on these pages):

No limitation

14 DESCRIPTORS:

a. EJC Thesaurus Terms: Thermal Imaging Logarithmic Amplifiers, Amplifiers, Thermal Imaging Non Linear Function Generators, Scanners, Infra-Red Equipment, Television Systems, Cathode Ray Tubes

b. Non-Thesaurus Terms: Images, Function Generators, Infra-Red Scanners, Image Converters

15 COSATI CODES:

1705

16 LIBRARY LOCATION CODES (for libraries listed in the distribution):

SW SR SD AACA

17 SUMMARY OR ABSTRACT:
(if this is security classified, the announcement of this report will be similarly classified)

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Security classification of this page: UNCLASSIFIED